MULTIMEDIA UNIVERSITY®

STUDENT ID NO

MULTIMEDIA UNIVERSITY

FINAL EXAMINATION

TRIMESTER 3, 2022/2023

EME4016 – HEAT TRANSFER

(ME)

03 OCTOBER 2023
9.00 a.m. - 11.00 a.m.
(2 Hours)

INSTRUCTIONS TO STUDENT

1. This Question Paper consists of six pages including the cover page and appendix.

2. Answer ALL four questions. Each question carries 25 marks and the distribution of the marks for each question is given in brackets [ ].

3. Write all your answers in the Answer Booklet provided.

Question 1

A large metal plate of thickness L at a uniform temperature T_i = 20℃ is put into a furnace at temperature, T_∞= 900℃. *The outer surface of the plate is well insulated.* Heat transfer to the plate is characterized by a convection coefficient, h= 200 W/m^2·K. It is given that L = 5 cm, plate density, ρ = 8500 kg/m^3, plate specific heat c_p = 380 J/kg·K, and plate thermal conductivity, k = 111 W/m·K. Assume that the temperature distribution is a function of spatial coordinate x, defined along the thickness of the plate, with the origin located at the outer surface, and time, t.

(a) Determine the time required for the temperature of heated surface of the plate ($x = L$) to increase to 140 ℃ by using one-term approximation. **[12 marks]**

Note: You may find the following one-term approximation equations useful:

1. $\theta^* = \theta_o^* \cos(\zeta_1 x^*)$,

where θ_o^* represents dimensionless temperature of the plate at $x^* = 0$ and

$\theta_o^* = C_1 \exp(-\zeta_1^2 Fo)$.

C_1 and ζ_1 are coefficients depending on Biot number.

Fourier number, Fo and the dimensionless variables are defined as

$$\theta^* = \frac{T - T_\infty}{T_i - T_\infty},\ x^* = \frac{x}{L},\ Fo = \frac{\alpha t}{L^2}$$

2. The coefficients for the one-term approximation are given as follows:

Bi^*	ζ_1 (rad)	C_1
0.01	0.0998	1.0017
0.02	0.1410	1.0033
0.03	0.1723	1.0049
0.04	0.1987	1.0066
0.05	0.2218	1.0082
0.06	0.2425	1.0098
0.07	0.2615	1.0114
0.08	0.2791	1.0130
0.09	0.2956	1.0145
0.10	0.3111	1.0161
0.15	0.3779	1.0237
0.20	0.4328	1.0311

(b) Determine the time required for the plate to increase to 140 ℃ by using lumped-capacitance method. **[7 marks]**
Note: You may find Appendix A useful.

(c) What is the physical interpretation of Biot number, Bi ? *Explain* for cases where Bi>>1 and Bi<< 1. Hence, *comment* on the discrepancy between the time found in part (a) and part (b). **[6 marks]**

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Question 2

In a system providing hot water, water is heated from 20 °C to 70 °C as it flows through a 1.8-cm internal diameter and 8-m long tube at a rate of 2×10^{-4} m^3/s. The tube is equipped with an electric resistance heater that provides *uniform heating* throughout the surface of the tube. Assume that at steady operation all the heat generated in the heater is transferred to the water in the tube and the flow in the tube is *fully developed at the exit.*

(a) Determine the power rating of the resistance heater. **[6 marks]**
(b) What is the Reynolds number of the flow? **[6 marks]**
(c) Estimate the surface temperature of the flow at the exit. **[8 marks]**
(d) Sketch the *surface temperature,* T_s and *mean temperature,* T_m of the flow, respectively along the axial direction of the tube for both *thermally developing*, and *fully developed* regions, with clear labels. **[5 marks]**

Note:

1. You may find Appendix B useful.

2. Convection correlation for fully developed flow in a circular tube subject to the uniform heat flux:

Laminar: $Nu = 4.36$
Turbulent: $Nu = 0.023\ Re_D^{0.8} Pr^{0.4}$

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Question 3

(a) A hot surface, whose base temperature is T_b =180 °C is cooled in an air environment with T_∞ = 20 °C and a heat transfer coefficient, h = 15 W/m^2·K. An aluminum pin fin of 2 mm in diameter and 15 cm in length is metallurgically joined to the hot surface. The thermal conductivity of the fin is, k = 180 W/m·K. Assuming the fin is *long*.

(i) Show that the heat transfer rate from a *long* fin is, $q = \sqrt{hPkA_c}(T_b - T_\infty)$. All the symbols carry the usual meaning. **[5 marks]**
(Note: You may find Appendix C useful.)

(ii) Determine the heat transfer rate from the long aluminum fin. **[5 marks]**

(b) A parallel, concentric heat exchanger is designed to heat a chemical at a rate of 3.5 kg/s from 25 °C to 45 °C, with hot water supplied at a temperature of 90 °C, and a flow rate of 2 kg/s. The inner tube is thin-walled and has a diameter of 3-cm. Take the specific heats for the hot water and chemical as 4.18 kJ/kg ·°C and 3.8 kJ/kg ·°C, respectively and assume an overall heat transfer coefficient of 1250 W/m^2·K, determine:

(i) the heat transfer rate, **[3 marks]**

(ii) the exit temperature of water, and **[3 marks]**

(iii) the required length of the tube. **[9 marks]**

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Question 4

(a) Consider the radiative heat exchange inside a furnace in the shape of a cube with edges 2 m in length. The furnace is heated through the bottom surface, maintained at temperature T_1= 800 K. All the other surfaces are kept at 480 K. The bottom surface has an emissivity 0.9, while all the other surfaces have emissivity of 0.5.

(i) Draw a suitable thermal radiation network for this furnace, with clear labels. Leave the label in symbolic form. **[4 marks]**

(ii) Calculate the heat transfer rate from the bottom surface. **[10 marks]**

(b) Consider the radiation exchange among three surfaces, 1, 2 and 3. The heat transfer from surface 1 is 27,600 W, and from surface 2 is -2,130 W. The black emissive power at surface 1 is 13,614 W/m^2. The radiosity at surface 1 is 11,418 W/m^2. The area of surface 2 is 3.14 m^2, with a surface resistance of 0.478 m^{-2}. Surface 3 is a blackbody.

(i) Draw a suitable thermal radiation network for this heat exchange with clear labels. Leave the label in symbolic form. **[6 marks]**

(ii) Calculate the surface resistance for surface 1. **[2 marks]**

(iii) Calculate the heat transfer rate to surface 3. **[3 marks]**

Note: Take the Stefan-Boltzmann constant to be 5.67×10^{-8} W/m^2·K^4.

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Appendix A: Lumped Capacitance Method for transient heat conduction

$$\frac{T-T_\infty}{T_i-T_\infty}=exp\left[-\left(\frac{hA_{s.c}}{\rho\forall c}\right)t\right]$$

Appendix B: Properties of saturated water

Temp., T °C	Saturation Pressure, P_{sat} kPa	Density, ρ kg/m³ Liquid	Density, ρ kg/m³ Vapor	Enthalpy of Vaporization, h_{fg} kJ/kg	Specific Heat, C_p J/kg · °C Liquid	Specific Heat, C_p J/kg · °C Vapor	Thermal Conductivity, k W/m · °C Liquid	Thermal Conductivity, k W/m · °C Vapor	Dynamic Viscosity, μ kg/m · s Liquid	Dynamic Viscosity, μ kg/m · s Vapor	Prandtl Number, Pr Liquid	Prandtl Number, Pr Vapor	Volume Expansion Coefficient, β 1/K Liquid
0.01	0.6113	999.8	0.0048	2501	4217	1854	0.561	0.0171	1.792×10^{-3}	0.922×10^{-5}	13.5	1.00	-0.068×10^{-3}
5	0.8721	999.9	0.0068	2490	4205	1857	0.571	0.0173	1.519×10^{-3}	0.934×10^{-5}	11.2	1.00	0.015×10^{-3}
10	1.2276	999.7	0.0094	2478	4194	1862	0.580	0.0176	1.307×10^{-3}	0.946×10^{-5}	9.45	1.00	0.733×10^{-3}
15	1.7051	999.1	0.0128	2466	4186	1863	0.589	0.0179	1.138×10^{-3}	0.959×10^{-5}	8.09	1.00	0.138×10^{-3}
20	2.339	998.0	0.0173	2454	4182	1867	0.598	0.0182	1.002×10^{-3}	0.973×10^{-5}	7.01	1.00	0.195×10^{-3}
25	3.169	997.0	0.0231	2442	4180	1870	0.607	0.0186	0.891×10^{-3}	0.987×10^{-5}	6.14	1.00	0.247×10^{-3}
30	4.245	995.0	0.0304	2431	4178	1875	0.615	0.0189	0.798×10^{-3}	1.001×10^{-5}	5.42	1.00	0.294×10^{-3}
35	5.628	994.0	0.0397	2419	4178	1880	0.623	0.0192	0.720×10^{-3}	1.016×10^{-5}	4.83	1.00	0.337×10^{-3}
40	7.384	992.1	0.0512	2407	4179	1885	0.631	0.0196	0.653×10^{-3}	1.031×10^{-5}	4.32	1.00	0.377×10^{-3}
45	9.593	990.1	0.0655	2395	4180	1892	0.637	0.0200	0.596×10^{-3}	1.046×10^{-5}	3.91	1.00	0.415×10^{-3}
50	12.35	988.1	0.0831	2383	4181	1900	0.644	0.0204	0.547×10^{-3}	1.062×10^{-5}	3.55	1.00	0.451×10^{-3}
55	15.76	985.2	0.1045	2371	4183	1908	0.649	0.0208	0.504×10^{-3}	1.077×10^{-5}	3.25	1.00	0.484×10^{-3}
60	19.94	983.3	0.1304	2359	4185	1916	0.654	0.0212	0.467×10^{-3}	1.093×10^{-5}	2.99	1.00	0.517×10^{-3}
65	25.03	980.4	0.1614	2346	4187	1926	0.659	0.0216	0.433×10^{-3}	1.110×10^{-5}	2.75	1.00	0.548×10^{-3}
70	31.19	977.5	0.1983	2334	4190	1936	0.663	0.0221	0.404×10^{-3}	1.126×10^{-5}	2.55	1.00	0.578×10^{-3}
75	38.58	974.7	0.2421	2321	4193	1948	0.667	0.0225	0.378×10^{-3}	1.142×10^{-5}	2.38	1.00	0.607×10^{-3}
80	47.39	971.8	0.2935	2309	4197	1962	0.670	0.0230	0.355×10^{-3}	1.159×10^{-5}	2.22	1.00	0.653×10^{-3}
85	57.83	968.1	0.3536	2296	4201	1977	0.673	0.0235	0.333×10^{-3}	1.176×10^{-5}	2.08	1.00	0.670×10^{-3}
90	70.14	965.3	0.4235	2283	4206	1993	0.675	0.0240	0.315×10^{-3}	1.193×10^{-5}	1.96	1.00	0.702×10^{-3}
95	84.55	961.5	0.5045	2270	4212	2010	0.677	0.0246	0.297×10^{-3}	1.210×10^{-5}	1.85	1.00	0.716×10^{-3}
100	101.33	957.9	0.5978	2257	4217	2029	0.679	0.0251	0.282×10^{-3}	1.227×10^{-5}	1.75	1.00	0.750×10^{-3}

Appendix C: Temperature distribution for fins of uniform cross section

Tip Condition ($x = L$)	Temperature Distribution θ/θ_b
Convection heat transfer: $h\theta(L) = -kd\theta/dx\|_{x=L}$	$\frac{\cosh m(L-x)+(h/mk)\sinh m(L-x)}{\cosh mL+(h/mk)\sinh mL}$
Adiabatic $d\theta/dx\|_{x=L} = 0$	$\frac{\cosh m(L-x)}{\cosh mL}$
Prescribed temperature: $\theta(L) = \theta_L$	$\frac{(\theta_L/\theta_b)\sinh mx+\sinh m(L-x)}{\sinh mL}$
Infinite fin ($L \to \infty$): $\theta(L) = 0$	e^{-mx}

$\theta = T - T_\infty$ $\quad m^2 = hP/kA_c$

$\theta_b = \theta(0) = T_b - T_\infty$

End of Paper